International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13424-13428

Experience in Developing Intelligent Biodynamic Lighting

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Abstract

In this article, the authors want to share the scientific and production experience that has accumulated over the past 10 years. It is important that this area of lighting engineering, which can be called intellectual energy-efficient biodynamic health-improving lighting, is already shaping the development of fundamental issues of lighting engineering which must be solved and discussed in the scientific optical and lighting community. Biodynamic lighting sets the task of developing techniques for regulating and developing lighting control systems, determines the necessary technological capabilities which are based on the rapid development of modern LED technology.

In the program MARS-500, experimental studies were conducted on the regulation of chromaticity (spectrum of the lighting unit) for individual psychophysiological adjustment of a comfortable light-color medium to improve the program participants' ability to work. The obtained results made it possible to understand how the physiological parameters change with a change in the light-color medium, and also the technique and software for improving the human performance were understood [1-5]. The given researches allowed formulating the principles of area illumination in confined spaces. This technology was distributed in a slightly modified form for the production of biorhythmic light fixtures, which resulted in pilot projects at a school in Vladimir and offices in Salekhard. The development of this technology continued in medical facilities, where chromaticity control was used to improve the accuracy of visual work in surgical departments, as well as increase the efficiency. In addition, after the completion of the surgical operation, a light-color medium was used for relaxation and rest. This technology was implemented in surgical rooms in the Kulakov perinatal center, Moscow [7,8,9].

For several years already, at the exhibition "Light+Building" in Frankfurt am Main (Germany), manufacturers in Europe have defined a certain trend which is about taking care of one's own well-being and health (Human Centric Lighting) ("HCL") [6]. The control system usually includes functions of manual and automatic modes. In the concept of "Human Centric Lighting" the main word is "human", that is, a person and his health are the focus of attention. It is for people that such a lighting system creates comfortable conditions of a fundamentally new level.

The market mainly offers biodynamic solutions based on the circadian rhythm of a person determined by the spectrum of the sun. The spectrum of the sun depends on our hormonal system and the overall metabolic process [10]. Peter Blatner, director of the CIE department No.2 and head of the optical laboratory at the Swiss National Institute of Metrology, asserts that the spectrum should follow the solar spectrum. In addition, for school lighting, he recommends using fixtures with LEDs with light diffusers. Ideally, a matte diffuser is needed, but other types of diffusers including the popular prismatic one can also be used. And he does not see any problems in using lighting fixtures with light diffusers for LEDs in school institutions and of course a dynamic system is needed - the spectrum of the light source (LS) should follow the solar one, since we are accustomed to the natural LS - the Sun and its influence on us.

The use of LEDs is not prohibited, but in some cases their placement in schools, child care centers and hospitals is not recommended - which greatly hinders the development of new technologies. Let us turn to the basic indicators in lighting equipment. All standardization of lighting equipment is based on contrast sensitivity, color-determining ability and visual acuity of a person. The modern view of the physiology of vision has made many discoveries that are used in medicine and engineering approaches to obtaining and transforming visual information which for the person is basic and accounts for more than 90% of all processed information. In order to understand the psychophysiological processes taking place during visual and non-visual changes in a person, it is necessary to talk about the relationship of physiological and engineering models of the organ of vision which are used for practical purposes.

The purpose of calculation and design of a lighting unit (LU) is to create such a light-color medium of the illuminated room that could provide the lighting efficiency of this LU taking into account the physiology of vision, work hygiene, technology and lighting economics, as well as the minimum costs of electricity, other material resources and labor costs for the installation and operation of the LU. Such a calculation is possible to make in the presence of certain rules and norms for the implementation of the lighting unit, which would eventually allow obtaining the required quantitative and qualitative indicators of the LU.

The method of direct normalization provides for the regulation of those quantities that directly determine the performance of the lighting unit and is the most perfect and understandable way to establish parameters. One of these criteria is the level of visibility with a given reliability of the solution of the visual task, as well as visual performance. However, the available scientific and practical data do not allow us to establish a direct relationship between various indicators of the LU effectiveness and photometric values.

Therefore, in world practice, **the method of indirect rating** is most often used, when quantitative and qualitative lighting parameters are taken as regulated characteristics, and LU performance indicators are used only as a rating criterion. Performance indicators of the LU are determined by the functional purpose of the lighting unit. Illumination, brightness, illumination, cylindrical illumination, natural illumination coefficient are usually used as quantitative characteristics. The quality of lighting is regulated by such concepts as blindness and discomfort, uneven distribution of brightness or illumination in space, pulsation of the light flux, spectral composition and color-transmitting properties of the light source radiation.

To understand the principles of the normalization of lighting units, it is necessary to become acquainted with the basic functions of vision, which are most clearly manifested in the study of steady and unsteady visual processes. No design norms are possible without taking into account the diverse characteristics and functions of vision.

One of the important visual tasks of a person is to detect an object on some bright background, therefore, the concept of contrast sensitivity is introduced, which is the reciprocal of the minimum threshold contrast of the spot with an angular dimension of 50 angular deg. - $S_{к} = 1/ K_{пор}$**.** The ratio of the threshold brightness difference $\Delta L_{пор} = (L_{о} - L_{ф})_{пор}$ to the brightness of the background $L_{ф}$ is called the threshold contrast of the brightness of the object of observation with the background $K_{пор}= \Delta L_{пор}/ L_{ф}$ (in this case we are talking about single-color fields)**.**

The color-determining sensitivity of the organ of vision is determined by the inverse threshold of color determination (or color threshold), where the color threshold is the smallest difference in the color of the optically adjacent parts of the central part of the observer's field of view first identified with a given probability. The perception of color is a subjective sensation that cannot be measured objectively. For these reasons, the International Commission on Illumination (CIE) standardized color measurements by introducing the concepts of *color matching and color chart functions* (CIE, 1931). Figure 1 shows the color matching functions introduced by CIE in 1931. These three functions show that the color of any radiation source can be described by a set of three variables that are dimensionless quantities. It should also be noted that neither the color matching function nor the color chart is unambiguous. In fact, there are several options for color matching and color chart functions (Judd, 1951; Vos, 1978).

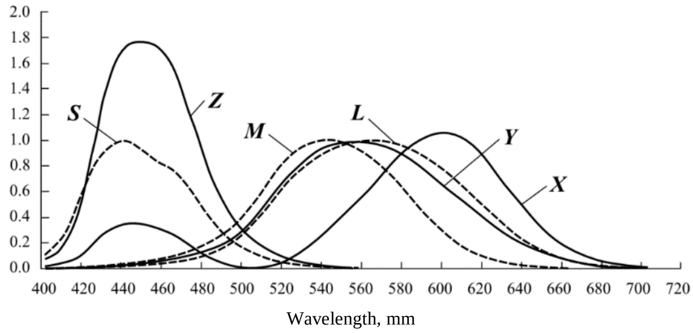

Figure 1: Color matching functions according to CIE 1931 (*XYZ*) and sensitivity of cones of three types (*SML*) (Wavelength, mm)

Since there is a clearly expressed correlation between the sensitivity functions of the retina cones and color matching functions (both groups of functions have three peak values, Fig. 1), we can assume that each set of color parameters *X*, *Y* and *Z* characterizes the approximate (but not exact) degree excitation of each group of cones of the human eye, when they hit the radiation from a source with an arbitrary spectral function. In colorimetry, color is understood as a three-dimensional vector quantity characterizing a group of visually indistinguishable radiations. In accordance with accepted scientific ideas about the essence of human color vision, color is uniquely determined by *the coordinates of the radiation color*. Colorimetry uses a color determination system based on the ability to reproduce a given color by additive mixing of the three primary colors in different proportions.

As contrast between the object of observation and the background increases, in comparison with its threshold value, the observation object on the background becomes more visible, therefore, the visual task is more likely to be solved, and the visual work is done with less stress.

In accordance with this reasoning, in lighting engineering practice, great importance is attached to the notion of the visibility level (VL), which is defined as the ratio of the observation object's contrast with the background to the threshold contrast value:

$$V_L = K/ K_{th}$$

The method for calculating VL to account for the quality of road lighting [12] is recommended by CIE [13,14] and adopted by the Committee of Road Lighting of the Illuminating Engineering Society of North America (IESNA) [15] and is used to quantify the quality of road lighting. The approved standard [15] uses the technique of W. Adrian to calculate the visibility of small objects. VL of objects located along the highway in front of the driver is calculated.

Man is the final link that makes a decision based on the visible image, i.e. information that he acquires being in one or another light-color habitat. To calculate the necessary visual information, mathematical models based on experimental data are used. Models do not accurately reproduce all processes occurring in the organ of vision (OV), but allow predicting a person's visual response to the resulting image. OV models can be divided into two main classes [16 - 32]: engineering, allowing calculating the possibility of obtaining visual information (empirical, informational, statistical) and physiological, allowing describing the neurophysiological processes taking place at all stages of visual information processing in OV.

Empirical models are widely used in lighting engineering, since the organ of vision was directly taken as the radiation receiver.

A huge amount of experimental data was obtained by Blackwell [33]. These data on the contrast sensitivity and visibility level were taken as a basis for rating in lighting engineering and were used for many engineering empirical models.

To understand the physiology of the visual process, special attention should be paid to the LMS-model, which is very important for considering the spectral characteristics of the light source and especially the LEDs. In light engineering, color is determined in accordance with the three-component Young-Helmholtz theory [34]. Along with it, the theory of E. Goering appeared, which until recently seemed incompatible, suggesting that there are three opponent processes in OV: one for sensing red and green, another for yellow and blue, and the third, qualitatively different from the first two, for black and white. Yellow, blue, red and green can be considered "basic" colors in such a system. According to Goering's theory, the black and white process involves spatial comparison, while its yellow-blue and red-green processes occur in one particular area of the field of view and are not connected with the environment. Black and white are indeed represented in the retina and in the brain by spatially separated processes of excitation and inhibition (on-off). Thus, the Young-Helmholtz representations can be interpreted as true for the level of retinal receptors, and Goering's ideas about the component processes for subsequent levels of OV. In support of the Goering theory, two types of cells with color-opponent receptive fields were found in the brain, as well as a third class that does not possess this property, but has wide spatial opposition [11]. In the higher regions of the striatal cortex, there is a separation of the perception of color and form. The study of neurons in OV confirmed the existence of three mechanisms of color perception: a brightness space-frequency, color space-frequency and color measurement mechanism. In this case, the color space-frequency mechanism with two opponent channels is insensitive to high frequencies. This feature can explain such phenomena of color vision as the absence of a blockage in the low frequency region, the absence of Mach stripes in the color image, the vagueness of the color uniform contour, the fusion effect of the bands of the high-frequency color grating, the assimilation of small colored objects by large ones.

Based on these data, the color physiological OV models identify signals of three types of cones - sensitive in the short-wave (S), medium-wave (M), and long-wave (L) parts of the spectrum [35]. Their contrast sensitivity is shown in Fig. 2.

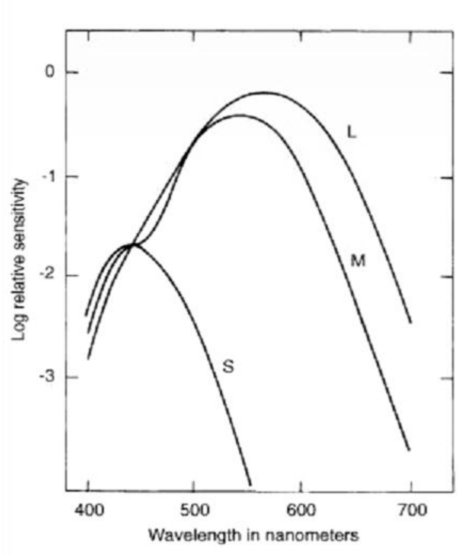

Figure 2: Spectral contrast sensitivity of three types of cones: sensitive in the short-wave (S), medium-wave (M) and long-wave (L) parts of the spectrum.

The block diagram of the opponent model is shown in Fig. 2 [35]. Three signals from the cones (L, M, S) at the level of the lateral geniculate body are redistributed into data for color and luminance channels. At the level of the cerebral cortex, a color channel, a spatial achromatic channel and a time channel are allocated. Such a model qualitatively describes the nonlinearity of the transformation of information of OV. Solid lines indicate well established links, while dotted lines are ambiguous.

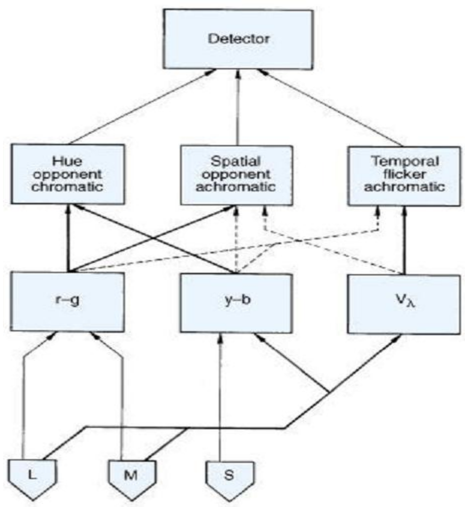

Figure 3: Opponent model of OV [35].

Opponent models cannot describe visual phenomena when an object changes location in space, because the wavelength is the only explicit variable of the stimulus. Nevertheless, colored opponent models successfully explain important psychophysical data, represent a very necessary synthesis of competing Young-Helmholtz and Goering theories.

Hubel and Wiesel [35] showed that the connections of the receptive fields of the organ of vision are formed precisely in the human visual brain. And in the same place, there are nonvisual links that determine the hormonal dependencies and metabolism, which is largely related to the light-color environment of human habitation. When a dispute arises in the lighting field that one or another spectrum needs to be removed or prohibited - this is the introduction of visual information into the discomfort processing area and the disturbance of psychophysiological processes. The main thing is not to prohibit any part of the spectrum, but to harmonize the work of the visual brain and create a comfortable, health-improving light-color environment for a person using the accumulated knowledge and physiology of visual perception and engineering approach to create lighting unit control systems.

Our experience gained in the scientific and practical development of intelligent biodynamic illumination shows that it is necessary not only to take into account the change in the spectrum of the sun, but also to take into account the harmonization of the spectral composition and psychophysiological state of a person for their successful activity when using artificial lighting.

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